

UNCLASSIFIED

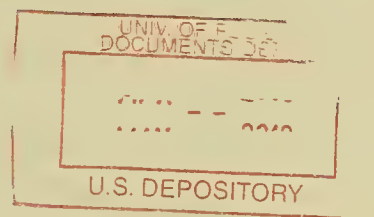
LA-1942

Subject Category: PHYSICS

UNITED STATES ATOMIC ENERGY COMMISSION

A BRIEF DESCRIPTION OF A ONE
MEGAWATT CONVECTION COOLED
HOMOGENEOUS REACTOR—LAPRE II

By
L. D. P. King



April 13, 1955

Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico



Technical Information Service, Oak Ridge, Tennessee

UNCLASSIFIED

Date Declassified: August 17, 1955.

The Atomic Energy Commission makes no representation or warranty as to the accuracy or usefulness of the information or statements contained in this report, or that the use of any information, apparatus, method or process disclosed in this report may not infringe privately-owned rights. The Commission assumes no liability with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

This report has been reproduced directly from the best available copy.

Reproduction of this information is encouraged by the United States Atomic Energy Commission. Arrangements for your republication of this document in whole or in part should be made with the author and the organization he represents.

Issuance of this document does not constitute authority for declassification of classified material of the same or similar content and title by the same authors.

Printed in USA, Price 20 cents. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

A Brief Description of a One Megawatt Convection

Cooled Homogeneous Reactor -- Lapre II

By L. D. P. King

Foreword

This report has been prepared primarily to assist the Reactor Safeguard Committee in evaluating LAPRE II. This reactor is a simplified convection version of LAPRE I which has been previously described for this Committee in LAMS-1611. The location is completely outside of any building and will only make use of the existing facilities for handling contaminated liquids or gases.

Geographic, meteorologic and seismic data are the same as for LAPRE I and were fully described in LAMS-1611. No further material of this type has been included here.

Work performed under Contract No. W-7405-Eng-36.

I. The Design and Operation of the Reactor

A. General Purpose

It is proposed to construct a simplified convection version of LAPRE I as soon as possible. The construction of such a unit is to help provide the Los Alamos Power Reactor Program with important information.

1. A long-term test of the corrosion and other properties of uranium phosphate solutions under actual operating conditions is absolutely essential before such solutions can have any practical value as a reactor fuel.

2. A one megawatt convection cooled homogeneous reactor using a uranium and phosphate solution might well serve as a pilot model for a very compact, simple and reliable portable reactor. LAPRE II is to be operated more or less continuously for an extended period unless obvious faults develop. There is to be a minimum of instrumentation and gadgetry. No operator is to be in attendance except for startup or during changes in running conditions.

B. Reactor Location

The location of LAPRE I in a cell of the main TA-35 laboratory has been fully described in LAMS-1611. It is proposed to place LAPRE II outdoors in a hole in the ground. Figure 1 shows the general location relative to the building and LAPRE I. The entire reactor core will be placed in the bottom of a steel tank approximately 20 ft deep and 42 in. in diameter. The upper portion of the tank will be filled by a 9 ft concrete plug sealed to the tank. The top of the tank and plug are at ground level.

C. Solution Properties

The solution chosen for LAPRE II is somewhat different from that planned for LAPRE I and described in considerable detail in LAMS-1611. A comparison of some of the properties of the two types of solutions is given in the table below.

	<u>LAPRE I</u>	<u>LAPRE II</u>
Composition of soup	0.6 M U + 7.5 M H_3PO_4	0.3 M U + 17.5 M H_3PO_4
Vapor pressure at 430°C	3900 psi	< 500 psi
Relative recombination rates at 430°C	1	25
Corrosion resistant materials at 430°C	Pt, Au, graphite	Pt, Au, graphite, Ag
Additional materials at 100°C	Stainless steel	Cu, stainless steel

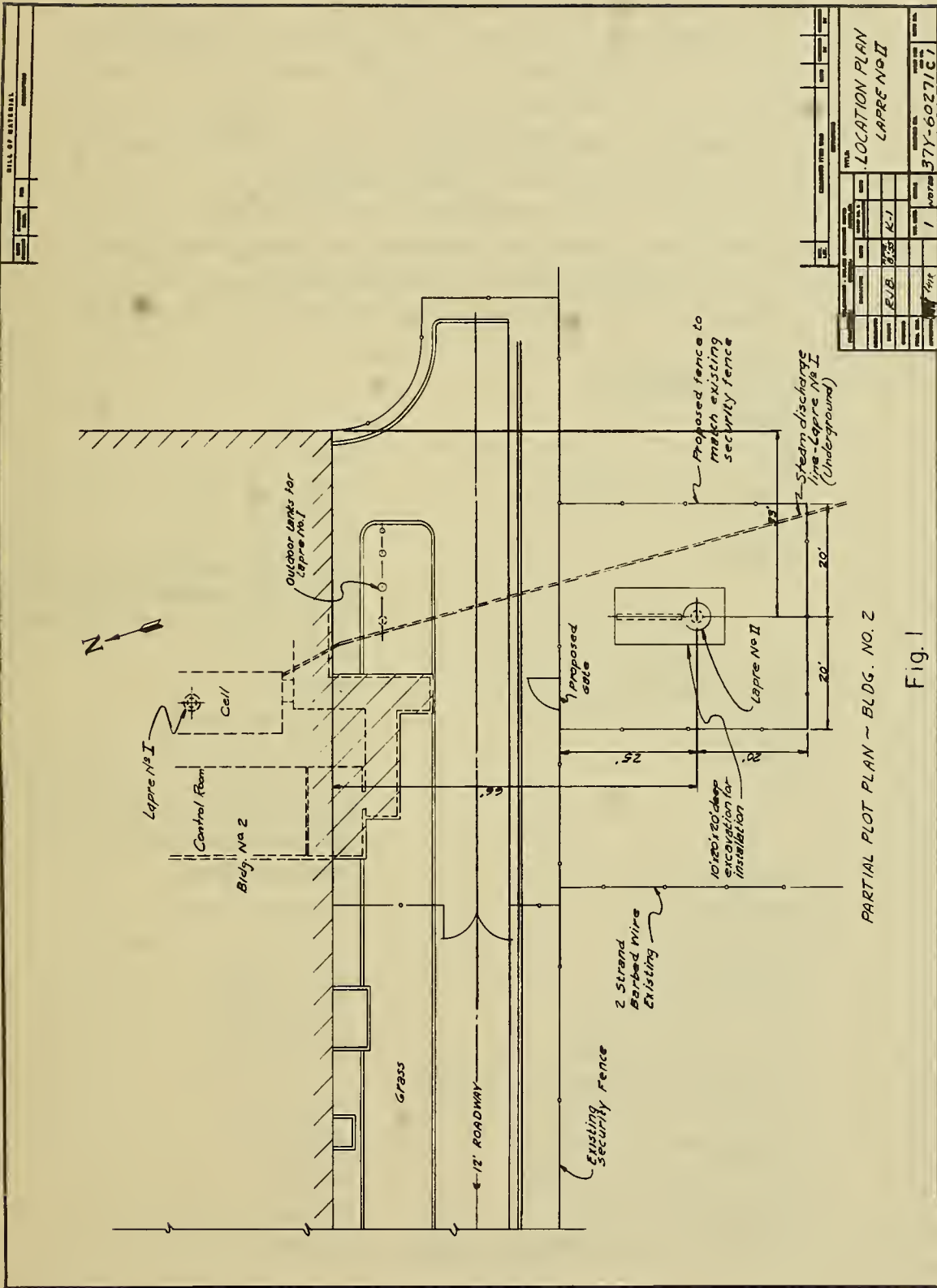


Figure 2 illustrates relative liquid filling levels vs. temperature for 98% and 91.6% phosphoric acid solutions. These bracket the proposed 95% solution for LAPRE II. An initial reactor filling of about 80% should give an approximate filling of 95% at the operating temperature of 430°C.

Figure 3 compares preliminary hydrogen and oxygen recombination rates over solutions with low and high concentrations of phosphoric acid. Actual radiolytic gas recombination rates measured under reactor operating conditions, for the low acid concentration case, have shown that the rates given in Fig. 3 are low due to the poor mixing conditions existing during the experiments. An overpressure of less than 20 psi is expected from radiolytic gas production for the LAPRE II solution.

D. Reactor Specifications

1. General

Name	LAPRE II
Location and operation	TA-35, Los Alamos Scientific Laboratory
Purpose	Life test of corrosion protection technique; demonstration of safety and feasibility of convection cooled power package reactor.
Type	Homogeneous
Neutron energy	Thermal
Status	Design in progress
Power	0.8-1 Mw heat
Fuel	UO ₂ (~90% U ²³⁵) dissolved in H ₃ PO ₄ , operated with 200 psi hydrogen overpressure.
Moderator	Water and H ₃ PO ₄
Reflector	Graphite (11 in.)

2. Reactor Vessel

Overall volume	104.7 liters
Vapor region volume	7.3 liters
Core region volume	62.6 liters
Overall length, bottom of vessel to top of top flange	56-3/4 in.
Inside diameter of vessel	14-3/4 in.
Wall thickness of vessel	5/8 in.
Height of core region	24 in.
Height of heat exchanger region	~ 15 in.

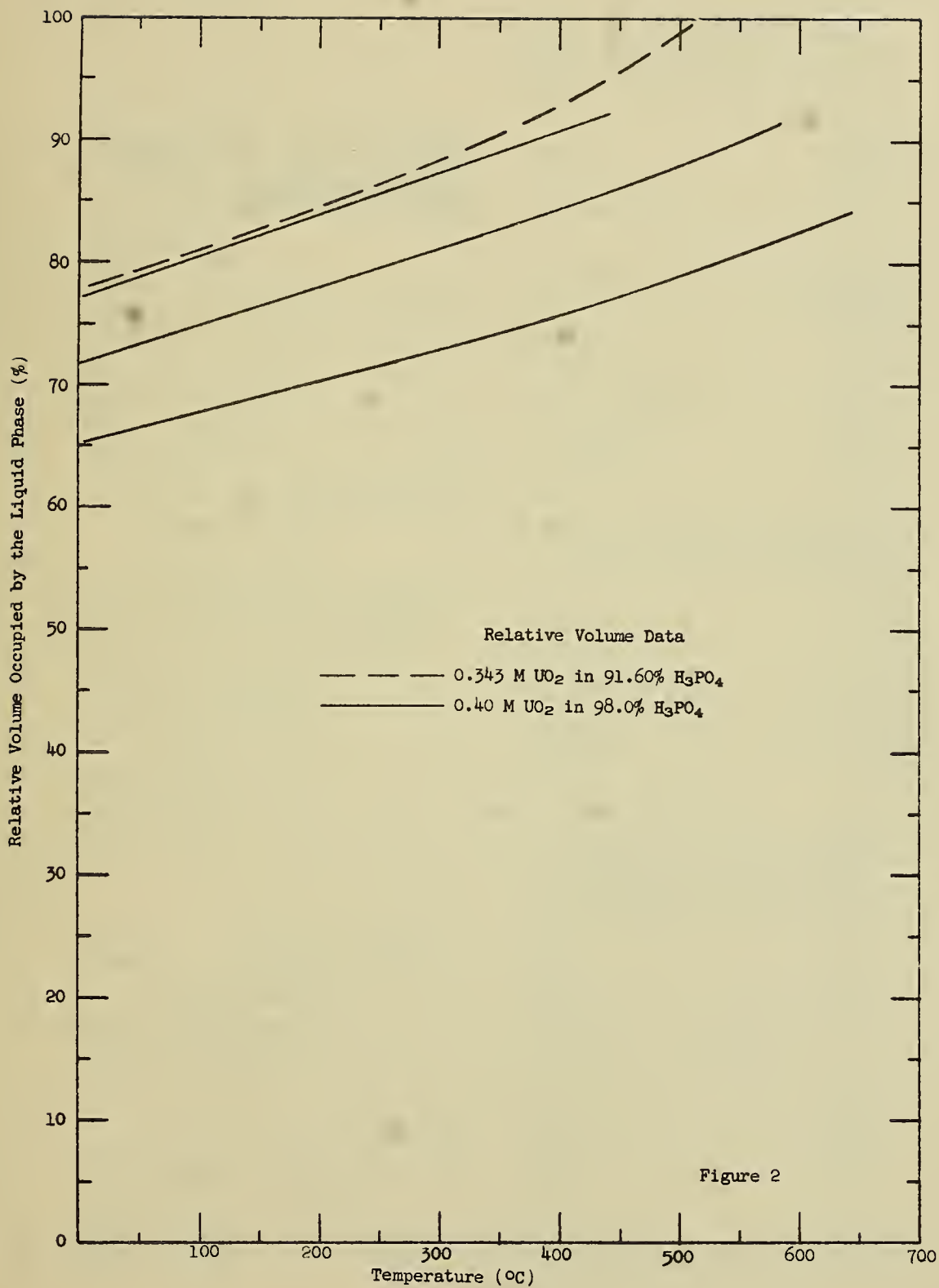
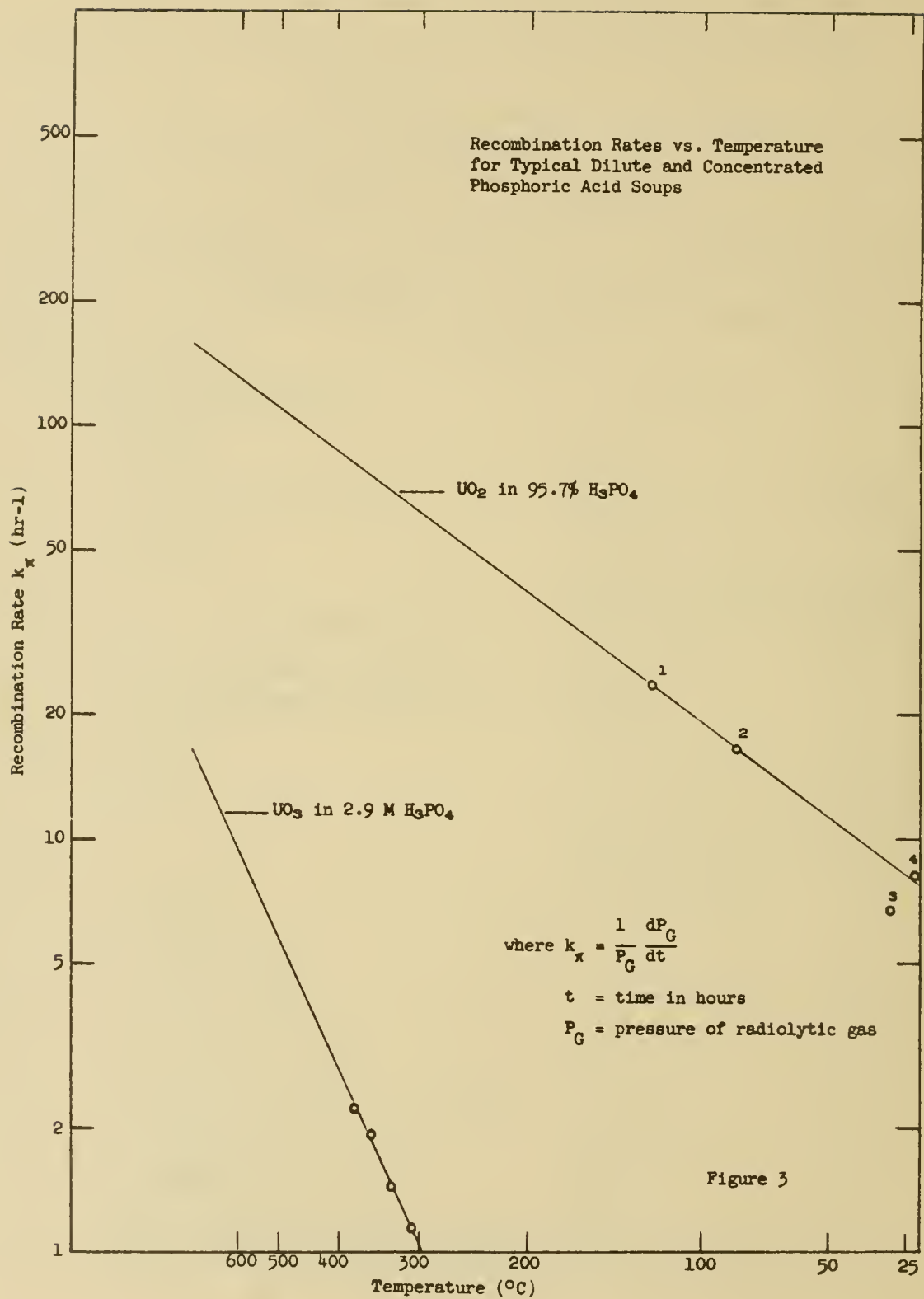


Figure 2



Vessel material	Stainless steel or A-336 F-22 steel (2-1/4% Cr, 1% Mo) clad/plated with Ag and Au.
Vessel closure	Metal O-ring plus seal weld
Working pressure limit for vessel at 430°C	1300 psi
Pressure and temperature in vessel at yield point of steel	2300 psi, 505°C
3. <u>Fuel Solution</u>	
Composition	~ 0.3 M UO ₂ in 17.5 M (95%) H ₃ PO ₄
Fuel solution volume at operating temperature (430°C)	97.4 liters
Fuel solution volume at room temperature (20°C)	≈ 82.5 liters
Power density (based on core region of 62.6 liters)	16 kw/liter
Fissionable material inventory	
Maximum: (0.4 M)	~ 7.70 kg--reflector shim out
Minimum: (0.2 M)	~ 3.85 kg--reflector shim in
Vapor pressure of fuel solution at operating temperature (430°C)	< 800 psi
Density of fuel solution (25°C)	≈ 1.85 g/cc
H:U in fuel solution	208 for 0.3 M UO ₃
Radiolytic gas evolved	Adequately removed by back reaction.
4. <u>Heat Exchanger</u>	
Area (outside surface of tubing)	30.6 ft ² (for 0.8 Mw)
Composition	43 helical and 1 spiral coil; 21 ft of 3/16 in. O.D. x 1/8 in. I.D. stainless steel, precious-metal-clad tubing per coil.
Coolant	Water
Coolant flow rate	2180 lb/hr at 0.8 Mw (4.36 gal/min)
Coolant temperature	70°F inlet, 600°F outlet
Coolant pressure	600 psi outlet
Coolant pressure drop through tubes	≈ 100 psi
Overall heat transfer coefficient	310 Btu/hr/ft ² /°F
Method of fuel circulation	Natural convection
Fuel solution circulation velocity	1/2 ft/sec
Heat disposal	Reactor coolant water to secondary heat exchanger to air radiator or evaporative cooler

5. Reactor Control

Shim control

Movable 6 in. thick annular graphite sleeve around reactor vessel. Total calculated reactivity effect of 11%. Maximum removal rate $\frac{\Delta k}{\Delta t} = 10\%/sec.$

Safety

Excess pressure in reactor vessel returns fuel to non-critical reservoir of 110 liter capacity.

If overpressure exceeds desired value, excess is vented to waste disposal system through duplicate relief valves.

Manual vent valve stops reactor by lowering fuel into reservoir.

Fuel input rate controlled by (1) a flow-limiting orifice on pressurizing gas line, (2) preset pressure on injection line to reactor. Fuel input rate will be limited to 1200 cc/min or a $\frac{\Delta k}{\Delta t} = 10\%/sec.$ Fuel ejection rate from reactor for a 500 psi overpressure empties upper 12 in. of reactor in about 25 sec for a calculated decrease in reactivity of about 10%.

Other

Excess criticality for two year operation handled by burnable poison (boron and lithium). Xenon override by solution temperature and/or shim.

6. Shielding

Earth fill (rhyolitic tuff $\rho = 1.4$). Exclusion area to insure 25 ft of earth between reactor and personnel. Reservoir tank and secondary heat exchanger also underground. It is estimated that both gamma and neutron dose rates will be below tolerance outside the exclusion area with the reactor at full power. Inside the fenced area the gamma dose rate could be several r/hr and this region will therefore not be accessible until the reactor power is reduced.

7. Flux

Fast average 6.1×10^{13} n/cm²/sec;
thermal average 1.2×10^{13} n/cm²/sec.
This assumes 68% of LAPRE I fluxes.

E. General Description

The aim in designing this reactor was to make it as simple, reliable and foolproof as possible.

Figure 4 shows a cut through the reactor proper. An overall layout of components is indicated in Fig. 5.

Since the vapor pressure is low, a thin-walled vessel can be used for the reactor, and solution transfer can be easily accomplished, even at full operating temperatures, by gas pressures less than 1000 psi.

The solution is highly corrosive for most materials and satisfactory pinhole-free plated surfaces are difficult to achieve. Due to the simple vessel shape and elimination of all internal vessel components except the heat exchanger, cladding of the vessel looks quite feasible. Either a heavy 0.060 in. silver cladding plated with 0.005 in. of gold or an all gold cladding approximately 0.010 in. thick will be used.

The reservoir tank which is cooled by a convection water loop will not exceed 100°C temperatures and can therefore be made of copper or stainless steel. The capacity of this tank is slightly greater than that of the reactor vessel so that all the solution can be held without danger of losing fuel out the over-pressure relief line.

The relief lines from the reservoir and enclosure tanks run into the contaminated disposal system available at TA-35.

The reflector consists of two concentric cylinders of graphite each cut from a single piece.

The use of a secondary heat exchanger completely isolates the radioactive portion of the reactor from the heat load. No instrumentation except for thermocouples and the primary feedwater pump exists in the reactor region. The latter may be replaced by a steam jet pump. Power control is obtained by the rate of coolant flow in the secondary loop.

Any neutron detectors or irradiation facilities will be placed in vertical thimbles outside of the entire reactor unit. A single sealed vertical rod will extend through the top shield plug to permit slow motion of the reflector shim sleeve. The outer tank will be gas tight and filled with nitrogen.

A small polonium-beryllium source placed under the reactor is used for initial startup; thereafter the beryllium oxide block becomes the primary background neutron source.

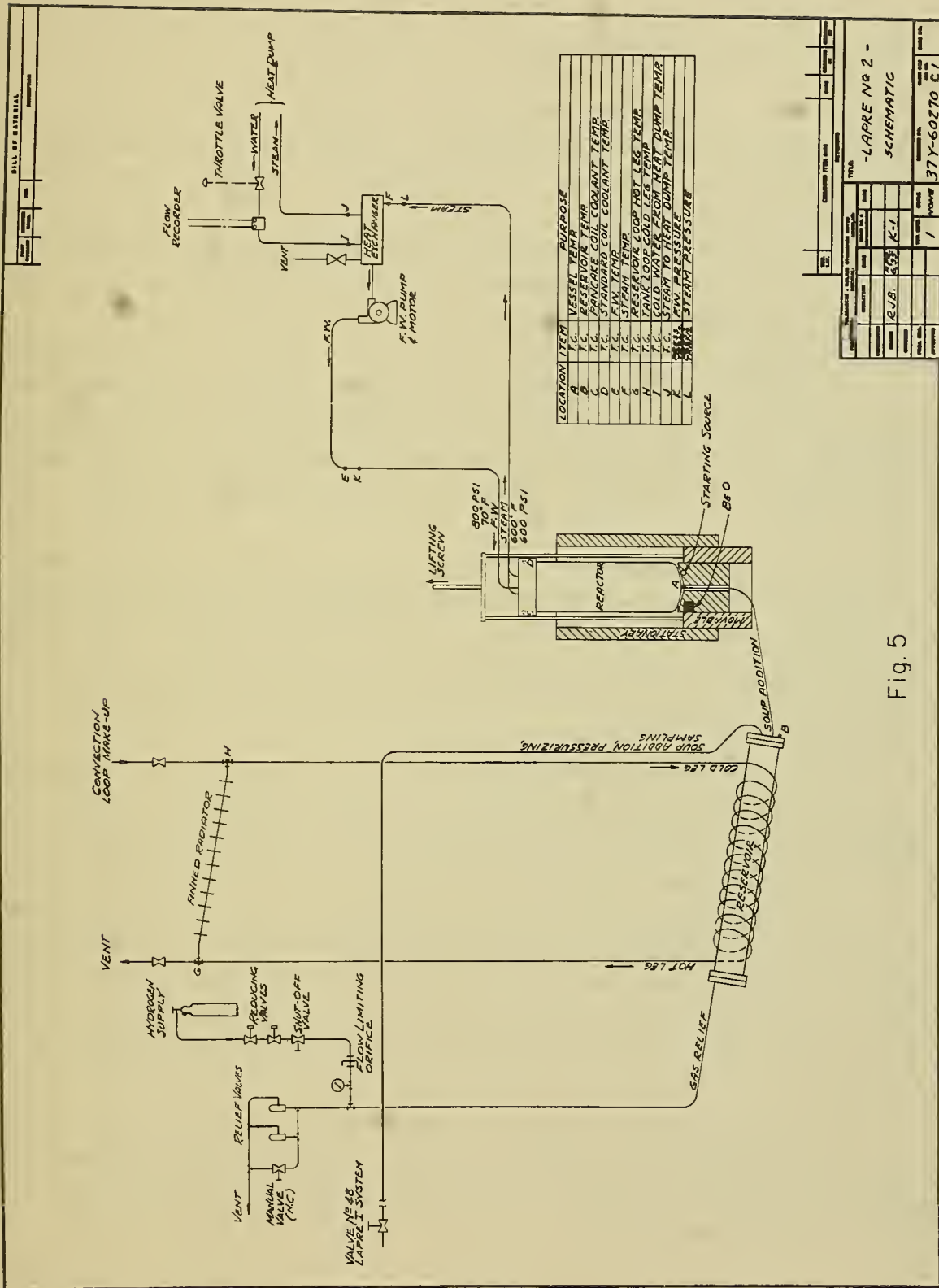


Fig. 5

The entire reactor reflector and outer tank will be at approximately reactor temperature during operation due to the good insulation properties of the ground.

Hot and cold feedwater lines are well separated to reduce vessel strains. The cold water flows into the central header and steam leaves at a peripheral header near the flanges. The flange seal is removed from the high radiation field.

An independent convection loop with air radiator is at all times available to take care of the fission product heating if the solution is discharged into the reservoir tank.

F. Operation

Initial startup will be carried out with the reflector shim about two-thirds in and the secondary feedwater loop set for low power. The reactor and reservoir tanks are pumped out through the gas sampling tube (Fig. 5). One Los Alamos atmosphere (~ 590 mm Hg) of hydrogen is then admitted to the entire system.

Solution is then added to the reservoir tank through the filling tube. The uranium concentration has previously been adjusted to the molarity calculated to be sufficient for about two year operation with a burnable poison. Sufficient solution is added to the tank so that when at operating temperature it would fill the reactor to 95% and a few liters remain to cover the connecting pipe with liquid.

The hydrogen tank with approximately 1000 lb maximum available pressure is opened through a reducing valve system. As a safety precaution, a flow limiting orifice is in the line which prevents the gas from forcing solution into the reactor tank at a rate which would exceed a reactivity change of $10\text{¢}/\text{sec}$.

Cold solution from the reservoir flows through the 1 cm I.D. pipe into the reactor at a rate controlled by the reducing valve pressure. When sufficient solution has gone into the reactor to reach the cold critical volume the solution begins to heat up at such a rate that its negative temperature coefficient $\sim (5.7 \times 10^{-4}/^{\circ}\text{C})$ uses up the excess reactivity produced by the further addition of solution.

Reactivity effects will be observed by the rise in solution temperature as indicated by thermocouple A, Fig. 5. One or more neutron chambers placed outside the reactor outer tank will also be used during initial startups to detect multiplication effects.

Thermocouple A will continue to show an increase in temperature throughout the solution addition period. When the reactor core proper is full, convection will begin, and thermocouple F in the primary heat exchanger loop will indicate a temperature rise. When the solution has reached the uppermost cooling coil layer, thermocouple C in the steam header will indicate a sharp rise. At this point the solution should be about at operating temperature. If the temperature is slightly off, the reactivity will be corrected by the reflector shim. If there is a substantial difference between design and actual temperature, the uranium concentration of the solution can be changed.

Reactor power can then be controlled by the throttle valve in the secondary loop. Temperatures from thermocouples I and J and coolant flow from the flowmeter will permit output power calculation.

It is hoped that the reactor can be maintained at full operating temperature and power for long periods of time. After initial testing no operator will be in attendance except for occasional routine checks.

II. Reactor Hazards

A. Potential Hazards

The following dangerous conditions might occur during operation of LAPRE II.

1. Rupture of the reactor vessel.
2. Rupture of a heat exchanger tube during operation.
3. Flooding of the reactor enclosure tank.
4. Reactor power oscillations due to solution transfer between the reactor vessel and reservoir.
5. Failure of a large portion of the vessel protective cladding.
6. Rapid reactivity increases caused by solution injection, reflector shim insertion, or full power demand from zero level.
7. Overheating of reservoir tank from fission product heat source.
8. Failure of coolant pump in primary or secondary loop.

B. Evaluation of Hazards

1. An experiment using a scale model indicated that if the reactor burst, the maximum pressure in the enclosure tank would be one-half the reactor pressure. An overpressure relief valve in the enclosure tank will take care of such a rupture. This relief valve will be set at about 250 psi and will vent into the waste disposal system available at TA-35.
2. Simulated rupture of a heat exchanger tube during operation was tested in a scale model. With the feedwater pressure exceeding the reactor pressure by 200 psi, only a 70 psi pressure rise due to water injection was observed. Since the feedwater and vapor pressures will probably differ by less than 200 psi, no appreciable pressure rise should be produced.
3. Accidental flooding of the enclosure tank during operation due to a ruptured feedwater line could build up high pressures from the vaporization of the water. The relief valve (see "2") will prevent rupture of the enclosure tank.
4. Calculations have shown that appreciable power oscillations cannot be induced in the reactor vessel through its coupling to the pressurized reservoir even for connecting pipes as large as 1 in. I.D. The choice of a 1 cm I.D. line is considered to offer no hazard in this respect.
5. Estimates based on corrosion data indicate that no large, rapid pressure surges can occur from the exposure of large areas of pressure vessel walls due to a failure of the cladding. A rate of about 0.2 psi/min/sq ft of exposed surface was obtained for stainless steel.

6. Calculations for maximum allowable reactivity variations indicate that rapid changes should not exceed \$1.00 in less than 1 sec. Reactivity adjustment rates were arbitrarily limited to one-tenth of this, i.e., 10¢/sec. The maximum safe solution injection rate based on 10¢/sec is 1200 cc/min. Rates will be limited to values below this by a flow restricting orifice in the pressurizing gas line.

The maximum safe reflector shim insertion rate, based on 10¢/sec, is about 10 in./min. The hand operated lead screw will be designed so that this rate cannot be exceeded.

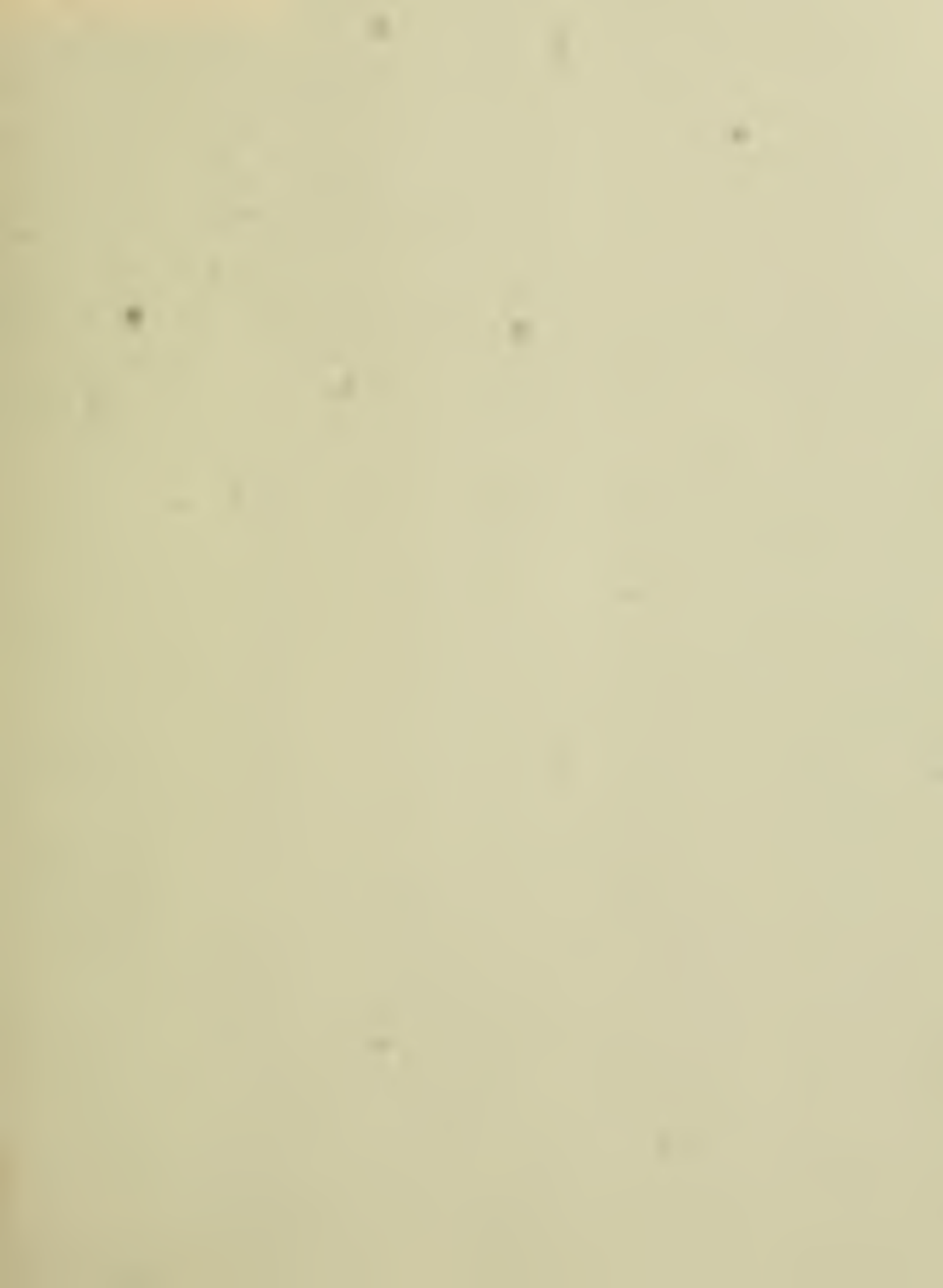
Calculations indicate that the peak power reached for a full 1.0 Mw power demand from a 10 watt level is about 11 Mw. The zero power level for the reactor will normally be at least 1-2 kw to maintain temperature. The maximum power overshoot for such an initial power will last for a few tenths of a second and will not exceed 6 Mw. The fuel temperature rise will be only a few degrees for such a burst.

7. If the entire volume of solution is discharged into the reservoir tank after long-period operation of the reactor, about 25 kw of heat would be produced in the reservoir from the fission products. An independent convection cooling loop and radiator system has been designed to hold the reservoir temperature below 100°C in such a case. The vapor pressure of the solution will not, therefore, rise to dangerous values when the fuel is dumped.

8. Failure of either the primary or secondary feedwater pumps will cause the fuel temperature and vapor pressure to rise; the reactor will then become subcritical and subsequent pressure and temperature rises will be at a lower rate, since only the fission product heat source remains. The rising pressure will discharge fuel into the reservoir until equilibrium is reached.

It is noted that most of the hazards listed are important because in some fashion or other, they can produce an overpressure in the reactor vessel. Setting the reservoir vent valves to release at the allowable working pressure for the vessel (1300 psi) should give adequate protection. The fuel discharge line appears to be large enough so that, once the reservoir vents, the pressure in the reactor vessel cannot continue to rise.

Contributions to the material covered in this report have been obtained from a large fraction of Groups K-1 and K-2. The following assisted in particular in obtaining data and evaluating the hazards: E. O. Swickard, R. E. Peterson, P. J. Bendt, R. M. Kiehn, J. R. Phillips, R. M. Bidwell.



UNIVERSITY OF FLORIDA



3 1262 08917 0871